RECENT ADVANCES IN ACTIVITY-BASED TRAVEL DEMAND MODELING

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ABSTRACT

This paper presents an overview of recent and on-going advances in activity-based travel demand modeling, organized in terms of the methodologies employed (including computational process models, structural equation model systems, and hazard-based duration models) and the phenomena being modeled (including in-home and out-of-home activity participation, interpersonal dependencies, and daily activity-travel patterns). The paper sets the overview of the recent and on-going advances in activity-based travel modeling in the context of the long and rich history of activity-based travel analysis, which was first proposed about 20 years ago as an alternative to the trip-based modeling framework and the discrete choice, utility-maximizing models that were being incorporated into the trip-based travel demand modeling framework at that time.

This paper finds that substantial progress has been made recently, and continues to be made, in advancing from activity-based travel analysis (with an emphasis on descriptive analysis and understanding), to activity-based travel forecasting models that can be used effectively for addressing contemporary policy and planning issues. The considerable recent effort and progress in activity-based travel modeling is attributed to technical, institutional and data availability factors.

1. INTRODUCTION

Twenty years ago, researchers at the Transport Studies Unit at Oxford University began seminal work in the development of an alternative travel demand modeling paradigm to the trip-based, four step modeling approach that was first developed during the early metropolitan land-use/transportation studies conducted in the U.S.A. in the mid to late 1950's. The alternative paradigm became known as the activity-based approach because it is based on the well known and long accepted idea that travel is a demand that arises through people's needs and desires to participate in activities. After many years of development, the activity-based approach to travel is ready for implementation at a time when the planning and policy analysis issues of the day cannot be suitably addressed by the existing, trip-based, four-step travel demand model.

The objective of this paper is to identify and document recent advances in activity-based travel demand modeling, while setting these advances in the context of the considerable history of development in activity-based approaches to travel modeling. The review of recent advances in activity-based travel modeling is organized in terms of the methodologies being developed and used and the phenomena being modeled. The review is not intended to be exhaustive in terms of the works described and cited, but it is intended to include a representative sample of recent and on-going work in the field in order to demonstrate the type and the extent of the advances being made.

The remainder of the paper is organized as follows. In the second section, we provide some background on the activity-based approach to travel demand analysis and modeling — readers already familiar with the development of this approach can readily skip this section. The third section of the paper provides an overview of recent advances in activity-based travel modeling, while the fourth section provides a brief discussion of the reasons that the activity-based approach to travel demand modeling has seen considerable progress of late. The final section of the paper presents some concluding thoughts.

2. BACKGROUND

The activity-based approach to travel demand analysis is founded on the well-known and long-accepted idea that travel is generally not undertaken for its own sake but rather to participate in an activity at a location that is separated from one's current location. The idea that travel is a derived demand has been accepted by travel demand modelers ever since it was first articulated by Oi and Shuldiner (1962) in their seminal work on urban travel demand. However, traditional travel demand models pay only lip service to this fundamental idea by segmenting trips by trip purpose and modeling the trips for different purposes separately.

The activity-based approach to travel demand analysis and modeling traces its roots to the seminal work on urban travel demand analysis undertaken in the mid to late 1970's at the Transport Studies Unit (TSU) at Oxford University under the leadership of Ian Heggie, working under a grant from the Social Sciences Research Council (Jones, *et. al.*, 1983). The activity-based approach was founded on the work undertaken previously by the sociologist and planner, F. Stuart Chapin Jr., at the University of North Carolina at Chapel Hill (Chapin, 1974), and by the geographer Torsten Hagerstrand at Lund University in Sweden (Hagerstrand, 1970, 1972). Kurani and Lee-Gosselin (1996) note that Chapin's work contributed by identifying patterns of behavior across time and space, while Hagerstrand's work delineated systems of constraints on activity participation in time-space. It is important to note the clear influence of fields other than economics in the development of the activity-based approach to travel demand analysis[1].

The development of the activity-based approach to travel demand analysis is characterized by a desire to *understand* the phenomenon of urban travel, not merely to develop predictive models that appear to produce acceptable forecasts. Proponents of this approach believed that one needed to have a good understanding of the behavioral phenomenon being modeled in order to develop sound predictive models. Much of the early work on the activity-based approach to travel demand analysis used in-depth interviews, with small samples, in an attempt to gain a good understanding of urban travel behavior. In particular, the HATS methodology (Jones, 1979), essentially a gaming simulation, was used very successfully by the researchers at TSU, Oxford, in trying to gain a better understanding of household level travel decisions and the constraints within which those decisions are made.

An early paper in the activity-based travel modeling literature by Heggie (1978), entitled “Putting Behaviour into Behavioural Choice Models”, argued that urban travel behavior is a complex phenomenon that could not be suitably represented in the discrete choice models (specifically logit models) that were gaining considerable popularity at the time the foundations of the activity-based approach were being put in place. Essentially, Heggie argued that while the discrete choice modeling framework provides a sound and rigorous approach to modeling the choice of an alternative from a set of available alternatives, the behavior being modeled at that time, primarily mode choice for the work trip, was not the correct behavioral phenomenon. In other words, a good tool was being used to address the wrong problem[2]. Most importantly, the discrete choice models that were being developed at that time, and that have dominated the field until recently, were not designed to be able to take account of dependencies among trips and between people, nor to account for constraints on activity participation and travel behavior.

The activity-based approach to travel demand forecasting can be considered the only real scientific revolution or paradigm shift, in Kuhnian (1970) terms, in the history of the development of travel demand forecasting models. The shift from aggregate to disaggregate models that took place starting in the 1970’s was a shift in statistical technique rather than a shift in the paradigm and thus can be considered an incremental change in the approach to travel demand modeling (for further discussion of this point, see Pas, 1990).

The activity-based approach to travel demand analysis encompasses many theoretical concepts and methodologies. However, the themes of the approach can be clearly discerned in the large body of activity-based travel demand research. In 1985 Pas described these themes as follows: (a) analysis of demand for activity participation (and the analysis of travel as a derived demand), (b) the scheduling of activities in time and space, (c) the constraints (spatio-temporal and interpersonal) on activity and travel choice, (d) the interactions between activity and travel choices over the day (or longer time period), as well as interactions between individuals, and (e) the structure of the household and the roles played by the household members. To this list, we should now add dynamics and adaptation to change as themes of the activity-based approach. Furthermore, as Kurani and Lee-Gosselin (1996) note, time use is becoming the focus of much activity-based research. (For an introduction to time use studies and their relationship to travel demand modeling, see Pas and Harvey, 1991, and for a more recent review, see Pas, 1996).

As noted above, much of the past effort in the activity-based approach to travel demand analysis and modeling has been devoted to developing a better understanding of the phenomenon of urban travel behavior, with less effort devoted to the problem of modeling and predicting this behavior. This research provides a very solid base on which the next generation of travel demand models is currently being built, as we now have a much better understanding of the phenomenon we are trying to model.

The interested reader can consult a number of review articles for additional, different perspectives on the activity-based approach to travel demand modeling, ranging from the early review prepared by Damm (1983), to the more recent reviews prepared by Kitamura (1988), Jones *et. al.* (1990), and Axhausen and Gärling (1992). For a recent discussion of the contribution of the activity-based approach to transportation policy analysis see Jones (1995), and for another perspective on the activity-based approach see the paper by Kurani and Lee-Gosselin (1996) in this volume. For an assessment of recent developments in household activity scheduling and the prospects for the future, see Kurani and Kitamura (1996).

3. RECENT AND CURRENT DIRECTIONS IN ACTIVITY-BASED TRAVEL DEMAND MODELING

In this section of the paper we discuss recent and on-going advances in activity-based travel modeling, This review is not intended to be comprehensive, but it does attempt to cover all the relevant directions being followed. The purpose of the review is to illustrate the directions being taken, and to show that advances are being made, not to provide a detailed account of recent and current research in any of the areas discussed here. This review is organized in terms of the methodologies being used and the phenomena being modeled, and we have attempted to include all the relevant methodologies being used and the phenomena being modeled, while providing a representative sample of work in each area covered.

3.1 Methodological Advances in Activity-Based Travel Modeling

One can readily identify a number of methodological areas in which advances have recently been made, and continue to be made, in the area of activity-based travel demand modeling. Some of these methodologies have been applied to travel demand modeling only recently, while other methodologies have seen application over a longer time period, but the phenomena to which they are being applied currently are new. The newer methodologies include computational process models, hazard-based duration models, and discrete-continuous choice models, while discrete choice and structural equation models are now being applied to a wider set of phenomena than in the past. These areas of methodological advancement are discussed in the sub-sections below.

3.1.1 Computational Process Models

One of the most interesting, and potentially powerful, new directions in activity-based travel modeling is the development and application of what are usually termed computational process models (CPM's). Such models are computerized implementations of what are known as production system models, which trace their origins to models in the psychology literature developed by Newell and Simon (1972). A production system model attempts to capture the decision-making process using a set of rules in the form of condition-action pairs.

The key point about CPM's is that such models attempt to represent explicitly the process used by the individual to make a decision, whereas in our conventional approaches to travel demand modeling, e.g., discrete choice models, the decision-making process is implicit in the model formulation. Computational process models allow for a variety of decision-making strategies, and allow the decision-making strategy of an individual to be different in different circumstances, while recognizing the human's limited information processing ability. Golledge *et. al.* (1994) note that CPM's have been developed in an attempt to "... replace the utility maximizing framework with behavioral principles of information acquisition, information representation, information processing, and decision making". They also point out that "... appropriate statistical techniques for estimating and calibrating CPM's are yet to be defined", but it should be noted here that some of the rules in a production system model can be based, for example, on discrete choice models.

Gärling *et. al.* (1994) discuss production system and computational process models and review the application of such models to activity scheduling behavior (including activity type, duration, sequencing, location and mode of travel). A number of CPM's are reviewed in their paper, including those dealing with information acquisition and representation in the context of navigation and route choice, as well as in the context of interrelated activity and travel decisions. CARLA (Jones, *et. al.*, 1983) and STARCHILD (Recker et. al, 1986a, 1986b) are the two early examples of such CPM-type models. CPM's have been applied primarily to the scheduling and rescheduling problems. In these models, the set of activities to be performed is generally taken as given. Recently, Pas (1996) suggested that CPM's might also be useful for the development of activity generation models if such models are to attempt to represent the process of activity generation.

One CPM has recently been applied in the U.S.A. at the metropolitan area level, in prototypical form. This model, known as AMOS (Activity-Mobility Simulator), is a component of the SAMS (Sequenced Activity-Mobility Simulator) model (Kitamura *et. al.*, 1996). The latter model was conceived by the RDC, Inc team in the FHWA-sponsored project "Redesigning the travel demand forecasting process" (RDC, 1993). The SAMS model is an integrated simulation model of land-use, sociodemographics, vehicle transactions, activity-travel behavior, network performance and air quality. The AMOS model, which is at the heart of the SAMS model, is described briefly below as an example CPM that has been applied to a real-world policy analysis situation.[3]

The AMOS model is an activity-based CPM that focusses on travelers' adaptation to policy changes. A prototype version of the AMOS model, designed specifically to deal with short-term responses to transportation control measures (TCMs), has been developed and applied in the Washington, DC area in a project sponsored by the FHWA and the Metropolitan Washington Council of Governments

(MWCOG) (see RDC, 1995, for a detailed description of this project and the results obtained). The development and application of the AMOS model in the Washington, DC area was designed to demonstrate how an activity-based travel demand model could be used to forecast commuters' short-term responses to the type of TCM measures being considered in the MWCOG region. Six policies were included in the study, as follows: (1) parking pricing, (2) improved bicycle and pedestrian facilities, (3) a combination of (1) and (2), (4) parking pricing with employer commuter voucher, (5) congestion pricing, and (6) a combination of (4) and (5).

This project used a 3-phase survey to collect information about the respondents' sociodemographic characteristics, their commute characteristics, their time use for a 24-hour period, and their stated response to the set of TCM measures listed above. The stated response section of the survey was customized to each commuter's work or school trip, in terms of the commute distance and travel time, and respondents were asked how they would respond to each TCM in the context of their activity and travel behavior on the previous day. The responses were coded into one of eight categories, as follows: do nothing, change departure time to work, change mode to carpool, change mode to transit, change mode to walk, change mode to bicycle, work at home, and other (e.g., long term changes). The stated response data was used to "train" (calibrate) a neural network to predict commuters' basic responses to the TCM measures, using sociodemographics, land use, transportation network and TCM characteristics. The calibrated AMOS model was applied to a small sub-sample of commuters from the 1994 MWCOG household travel survey, to predict the impacts (including the percent of cold starts) of the alternative TCMs.

In addition to AMOS, there are a number of other CPM's that have recently been developed or are currently under development. These models include SCHEDULER (Gärling *et. al.*,1989; Golledge *et. al.*, 1994), SMASH (Ettema *et. al.*, 1995b), and PCATS (Kitamura, 1996). Furthermore, in his development of an activity-based CPM of travel behavior, Vause (1995) is making a valuable contribution by developing techniques to assist in the formulation of the rule base used in the CPM.

3.1.2 Hazard-Based Duration Models

Hazard-based duration models were originally developed for, and applied to, problems in the fields of medical science and industrial engineering, but they have also seen extensive application in economics (primarily labor economics) and marketing. Since the late 1980's, hazard-based duration models have also been applied to a number of transportation-related phenomena, including travel demand. Hensher and Mannering (1994) provide a thorough review of the important concepts in hazard-based duration modeling and examples of the application of these models to transportation phenomena. They argue that hazard-based duration models provide the transport modeler with a powerful tool and they note that there have been surprisingly few applications of these models in transportation modeling, especially since transportation modelers routinely deal with duration-related phenomena.

Hensher and Mannering (1994) include in their review example transportation applications in the areas of accident analysis (time between accidents), car ownership modeling (time between households' vehicle purchases), traffic operations (time to restore a freeway to capacity after an accident, and vehicular delay at international border crossings) and travel behavior. Applications referenced by Hensher and Mannering in the latter area include the length of time travelers delay their departure from work in order to avoid congestion (Mannering and Hamed, 1990), the time travelers stay at home between activities requiring trips (Mannering *et. al.*, 1992 and Hamed *et. al.*, 1992), and the time until acceptance of a new tolled roadway (Hensher and Raimond, 1992).

The general idea of a hazard-based duration model is that it tries to model the conditional probability of "failure" at time t (i.e., the probability that the event of interest terminates at time t), given that failure has not occurred prior to this time (i.e., that the event has not terminated prior to time t).[4] Thus, for example, one might try to model the probability that a worker finds a job at time t (ending the unemployment period), given that s/he is unemployed up to this time.

The most relevant application of the hazard-based duration model in activity-based travel demand modeling is in connection with modeling the duration of activities and home-stay duration (time between returning home and leaving on another trip). In this connection, the most pertinent work is that of Neimeier and Morita (1996), Mannering and his associates (Mannering *et. al.*, 1992; Hamed *et. al.*, 1992), Ettema *et. al.* (1995) and Bhat (1996a, 1996b). However, another possible use of hazard-based duration models is in modeling the time until the next activity of a particular type occurs. Thus, with the appropriate data, one could model the time between, say, shopping activities.

As noted earlier, Mannering *et. al.* (1992) and Hamed *et. al.* (1992) have applied hazard-based duration models to model the length of time a traveler spends at home before making another trip. Specifically, this work deals with the amount of time a commuter spends at home after arriving home from work before leaving home to take part in another out-of-home activity. Neimeier and Morita (1996) developed a model for the duration of particular trip-making activities based on gender. The activities they studied include: household and family support shopping, personal business, and free time. Neimeier and Morita found no significant differences between the durations of men and women for the free-time and personal business activities, but gender was a very significant explanatory variable in the case of the household and family support shopping activities, with women being more likely than men to have longer durations for household and family support shopping activities. Hazard-based models have also been used to study the time that a car is stationary, with respect to being able to predict the probability of a cold-start (Ponnoluri, 1995).

A recently developed duration model, developed by Ettema *et. al.* (1995), deals with both activity duration and activity choice by using what is known as a "competing risk" hazard model. The authors estimated the model using data collected from a small sample of students, through an interactive computerized data collection procedure called MAGIC, which they have developed to investigate activity scheduling behavior (Ettema *et. al.*, 1993). The estimated model parameters show that spatio-temporal constraints such as time of day, opening hours and travel time, play an important role in activity scheduling. Activity duration and type were also found to be dependent on the history of the activity-travel pattern and the traveler's priorities. The authors conclude that the estimated model performs satisfactorily, and holds promise for describing activity scheduling as a continuous decision-making process, although further development is needed to deal with some important technical issues.

Bhat (1996a) has recently developed a hazard-based duration model of shopping activity duration on the trip home from work, while at the same time significantly extending the methodology of hazard-based duration models.[5] Bhat (1996b) has also recently developed a multiple durations (i.e., competing risks) model that extends the existing state-of-the art considerably. Thus, there are a number of recent examples of the application of hazard-based duration models to activity duration modeling and examples of methodological developments as well.

3.1.3 Structural Equation Models

Structural equation models have been applied in a number of areas of the social sciences for quite some time. This methodology has seen relatively little application in travel demand modeling in spite of its ability to facilitate the modeling of a large number of interrelated variables. Up until very recently, all the work in the application of structural equation models to travel demand modeling was conducted by Golob, who pioneered the use of this methodology in travel demand modeling, and his collaborators (see, for example, Golob and Meurs 1987; Golob 1990a, 1990b). However, other researchers have recently started using the structural equation models methodology to develop activity-based travel demand models (Fujii et. al, 1996; Lu, 1996), and Golob has extended the range of applications to which he has applied this methodology to include activity-based travel demand modeling (Golob, 1996; Golob, Bradley and Polak, 1996; Golob and McNally, 1995).

The current applications of structural equation models to travel demand make use of the methodology to capture some of the complex relationships considered important in the activity-based approach to travel demand. Fujii *et. al*. (1996), for example, use the methodology of structural equation models to model commuters' time use and travel after work hours using data collected in the Osaka-Kobe metropolitan area. Their model shows that of a 10-minute time "savings" for the commute trip, slightly more than 7 minutes will be used for in-home activities, thus bringing into question the idea of a constant travel time budget.

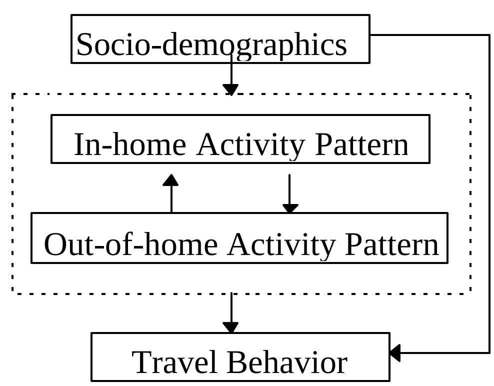
Golob and McNally (1995) develop a joint model of the out-of-home activity participation and travel of male and female couples (whether they are spouses or not) who are heads of households (see Section 3.2.2 below for more detail on this work). Golob (1996) uses the structural equation modeling approach to model demand for activity participation and mobility, and he includes one category of in-home activity (namely, work) in the model. The model is formulated to allow for a number of hypothesized behavioral phenomena including: travel demand derived from activity participation, time budget effects, mobility demand (activity participation affects vehicle ownership), and accessibility (vehicle ownership affects activity participation).

One recent application of the structural equation modeling methodology to activity-travel relationships is the work of Lu (Lu, 1996; Lu and Pas, 1997). In this work, a model relating socio-demographics, activity participation and travel behavior, at the individual level, is developed, estimated and interpreted.

A complex set of interrelationships among the variables of interest is estimated simultaneously using the structural equation model methodology implemented in LISREL (Joreskog and Sorbom, 1995).

An overview of the model developed and estimated by Lu is shown in Figure 1. This figure shows that activity participation (measured by the duration of activity participation in each of 4 in-home and out-of-home activity categories) and travel behavior (measured by the number of trips, number of trip chains, daily travel time, and percent of trips by car) are *endogenous* to the model (i.e., they are estimated within the model), while socio-demographic characteristics are the *exogenous* variables (or inputs) in this model. The figure also illustrates that the model allows for the *direct* effect of socio-demographics on travel behavior as well as for the *indirect* effect via activity participation (since socio-demographics can affect activity participation which in turn can affect travel behavior). The combination of the direct and indirect effects is known as the *total* effect of one variable on another in a structural equation model.

Figure 1: A Model of Sociodemographics[1], Activity Participation[2] and Travel[3]
Model Overview



[1] Socio-demographic characteristics included in this model represent household and personal characteristics. Household characteristics include number of workers, number of children, number of vehicles and income, while personal characteristics include age, gender, employment status and license holding.
[2] Activity participation is measured by the duration of in-home and out-of-home activities in each of four activity categories.
[3] Travel behavior is measured by the number of trips, number of trip chains, daily travel time, and percent of trips by car.

After: Lu and Pas (1997)

Lu's research shows that complex relationships among socio-demographics, activity participation and travel behavior do exist, and can be captured by the model structure employed in this research. Specifically, Lu and Pas (1997) reach the following overall conclusions. First, significant relationships among socio-demographics, activity participation and travel behavior can be simultaneously captured by the estimated model, and most of the estimated direct effects correspond with the historical findings. Second, travel behavior can be explained better by including activity participation in the model. Third, relationships between in-home and out-of-home activity participation do exist and can be estimated and interpreted. Finally, by examining the direct, indirect and total effects in the model system, we can better capture and understand the relationships among socio-demographics, activity participation and travel behavior, thereby demonstrating the usefulness of structural equations models in modeling the complicated relationships among sociodemographics, activity participation and travel behavior.

3.1.4 Discrete and Discrete-Continuous Choice Models

One approach to modeling some of the complexities in travel behavior emphasized by the activity-based approach to travel demand modeling is to use discrete choice or discrete-continuous choice models. Although originally developed and applied in the context of a trip-based framework, discrete choice models have been recently applied to sets of interrelated activities and travel. For example, Ben-Akiva and Bowman (1995) have recently developed a model in which they consider the daily activity-travel pattern as a set of tours. Each tour is assumed to have a primary activity and destination — the primary activity being the major motivation for the tour. Further, tours are sub-divided into primary and secondary tours. The daily activity-travel pattern is thus characterized by a primary activity, primary tour type, and the number and purpose of secondary tours. The tour models, which are conditioned on the choice of a daily pattern, include the choice of time of day (one of four discrete time periods), destination (discrete traffic analysis zones), and mode. The model is operationalized and estimated as a nested logit model, and could be used by an MPO with the capability of estimating a nested logit model. However, the model is quite limited in its spatial and temporal resolution.

Recent work by Bhat (1997) extends the usefulness of discrete choice models by developing a joint model of work mode choice and number of non-work stops during the work commute. Mode choice is modeled using an unordered choice model and number of stops is modeled using an ordered response formulation. The model has been applied to data from the 1990 Boston Area survey, and the results demonstrate the importance of accommodating the inter-relationship between mode choice to work and number of non-work activity stops in the work commute. The results of policy tests with the model show that commuters who make non-work stops on the work commute are unlikely to be drawn away from the drive alone mode.

Another interesting, relatively recent development in activity-based travel demand modeling results from the recognition that discrete choice models, as such, cannot deal with an important variable of interest in the activity-based approach, namely the duration of an activity, because it is continuous in nature. Although it is almost 10 years since Mannering and Hensher (1987) published a review article on discrete/continuous econometric models, and their application to transport analysis, it is only relatively recently that we see the development and application of this type of model in the context of activity-based travel demand modeling.

Both Hamed and Mannering (1993) and Bhat (1995) develop and apply discrete-continuous choice models to model post work activity participation behavior, while Kitamura *et. al.* (1996) develop and apply a discrete-continuous choice model to model the allocation of time to in-home and out-of-home discretionary activities (see Section 3.2.1 below). Hamed and Mannering develop a hazard-based duration model to examine home-stay duration after the end of the work day. They estimate a separate logit model of activity type choice, and linear regression equations for travel time to and from the out-of-home activity and the out-of-home activity duration.

Bhat (1995) develops a discrete-continuous model of post home-arrival activity participation behavior in which three inter-related choices are modeled simultaneously, namely (1) choice of next out-of-home activity, (2) home stay duration and (3) duration of the out-of-home activity. The model is estimated, using full-information maximum likelihood, for the case of post-home arrival from work behavior. Bhat's work advances the state-of-the-art in discrete-continuous models in that this is apparently the first case in which full information maximum likelihood has been applied to a discrete-continuous model when the discrete choice is polychotomous. Bhat's methodology also extends previous work by dealing with two continuous outcomes, not one, and it overcomes some of the limitations of Hamed and Mannering's framework.

3.1.5 Enhancement of Existing Travel Demand Models

One approach to improving existing travel demand models, in the short-term, is to make incremental changes to these models based on what we have learned about travel behavior from the activity-based travel research of the past 20 years. One can point to a number of influences that the activity-based approach has had on the development of trip-based, four-step models over the years. The improved specification of travel demand models, especially the incorporation of variables describing household structure (or what is often referred to as "lifecycle") is a good example of the influence of activity-based travel research on traditional travel demand models.

A very good recent example of the use of activity-based research results in making incremental improvements to existing travel demand models is to be found in the current round of model development by the Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area, based on data collected in the 1990 household travel survey conducted in the Bay Area. In this effort, Purvis and his colleagues (Purvis, *et. al.*, 1996) used research on time use to motivate a modification to their otherwise traditional non-work trip generation model. The new non-work trip generation model includes work travel time as an explanatory variable. The idea being that commuters who spend more time on the work commute have less time available to participate in non-work activities. Estimation results confirmed this hypothesis and work travel time was found to have a significant negative effect on non-work trip generation. Purvis *et. al.* (1996) interpret work travel time as a measure of accessibility, thus arguing that improvements in accessibility for the work trip will lead to increases in non-work trip generation and vice versa.

3.1.6 Summary of Recent Methodological Directions in Activity-Based Modeling

The discussion in this section demonstrates that in recent years there has been a considerable amount of work in the development and application of methodologies for activity-based travel demand modeling. This research and development work is rapidly moving the activity-based approach to travel demand modeling from one in which the primary focus is on descriptive analysis and understanding to one in which forecasting models are being developed and applied.

Some of the methodologies used in the activity-based approach to travel modeling are rather new to the field (e.g., computational process models), while others have seen some previous use in travel demand modeling (hazard-based duration models and structural equation models), and yet others are very familiar to the field (discrete choice models). In addition to providing an overview of the new methodologies, this section also points out that existing modeling approaches are being applied with the insights derived from the rich information base developed by activity-based researchers over the past 20 years.

While there are a number of methodologies being pursued at the present time, in the future researchers will no doubt combine the most appropriate methodologies to develop complete model systems. For example, Hensher (1996) and his colleagues are about to embark on a major research project in which they will develop an activity-based travel demand model system which takes into account travel time budgets, and the duration, sequence and chaining of activities. In this project, the researchers will develop competing risk duration models with generalized logit models to capture the diversity of activity choices and their sequence and duration.

3.2 Phenomena Being Modeled in Recent Activity-Based Travel Models

Many different phenomena are being modeled in current activity-based travel demand modeling work. In some cases, the methodology being used to model a particular aspect of urban activity-travel behavior does not fit into one of the areas discussed in the previous section, in other instances the methodology falls into one of the areas above and the work cited here also appears in the previous section. The purpose of the present section is to give the reader a sense of the range of phenomena being modeled, with a particular emphasis on those phenomena not mentioned in the methodologies section above.

3.2.1 In-Home and Out-of-Home Activity Participation: Trade-Offs and Relationships

The activity-based approach to travel demand modeling focusses attention on the need to be able to model which activities will be undertaken in the home and which will be undertaken outside the home (and thus generate travel), as well as the dependence between time spent at-home and out-of-home. A number of recent activity-based modeling studies have addressed these issues.

Kitamura *et. al*. (1996) formulate a discrete-continuous choice model of time allocation to 2 types of discretionary activities, based on random utility maximization. The model deals with in-home and out-of-home time allocated to discretionary activities. The model is formulated as a doubly-censored Tobit model, while requiring only the assumption that one of the activities is engaged in on the day in question (i.e., the person engages in some discretionary activity, either at home, out-of-home, or both.) The explanatory variables in the model are work schedules, commute characteristics, as well as residential, household and personal attributes. A weekly time use data set from the Netherlands is used in the empirical analysis, and the data are treated as repeated daily measurements. An error component is introduced into the model to deal with the heterogeneity in the data set comprising repeated measures of daily time use for each of the respondents. The model is estimated using a non-parametric approach, employing mass points.

The estimation results show that individuals who work on a given day tend not to engage in discretionary out-of-home activities. However, those who work more hours per week do tend to spend a larger fraction of their discretionary time out-of-home. Individuals who spend more time commuting spend more time on in-home discretionary activities. Gender does not, by itself, seem to affect in-home/out-of-home time allocation, but child rearing does. Larger households tend to be more in-home oriented, while income and number of vehicles and flexible work hours are not significant explanatory variables with respect to the allocation of time to in-home versus out-of-home activity participation.

Lawson (1996) is conducting dissertation research aimed at modeling the decision to undertake an activity in-the-home or out-of-the-home and explicating the factors that contribute to the decision. She has hypothesized that the explanatory factors include household composition, work characteristics, age composition and lifestyle status. Conceptually, the analysis is based on a utility maximization process, identified in the "new home economics" and applied to the allocation of household resources. Several different choice models will be estimated using the data from the Portland portion of the 1994/95 Oregon-Southwest Washington Household Activity Diary Survey. Lawson plans to capture interpersonal and interactivity effects in her model.

As a third example of recent research in which the relationships between in-home and out-of-home activity participation have been studied, we refer to Lu's (1996) work, which was described in more detail in Section 3.1.3 above. This work, using a structural equation model relating sociodemographics, activity participation and travel, showed clear dependencies between in-home and out-of-home activity participation, as well as the effect of sociodemographics on the decision of whether to spend more time at-home or out-of-home. Thus, for example, an increased number of children in the household was found to increase the time spent on at-home activities and simultaneously decrease the time spent on out-of-home activities. Therefore, the relationship between trip-making and number of children in the household is a rather complex one.

3.2.2 Interpersonal Dependencies

One of the tenets of the activity-based approach to travel modeling is that there are relationships between the activity-travel patterns of members of the same household. Early work at TSU Oxford showed clearly the existence and importance of interpersonal dependencies, and Townsend (1987) developed a framework for the development of such models. However, modeling these dependencies is particularly difficult, and only recently have researchers begun tackling this task.

Golob and McNally (1995) recently used the methodology of structural equation models (see Section 3.1.3) to develop a joint model of out-of-home activity participation and the resultant travel of male and female couples (married or unmarried) who are heads of households. The research aimed at identifying the interactions between activity participation and travel and between the two individuals being modeled. This research, using the data collected in the Portland area during the recent Oregon-Southwest Washington Household Activity Diary Survey (see Section 4.3 below), demonstrates the existence of, and provides quantitative estimates of the effects of out-of-home activity participation on travel behavior and the interdependencies between the male and female household heads in their activity participation and travel.

In addition to the work of Golob and McNally (1995) discussed above, we note here the on-going work of Lawson (1996) , which (as mentioned above) aims at capturing interpersonal dependencies in the context of in-home versus out-home activity trade-offs. The reader should also note that Wen (1996) aims at incorporating interpersonal interdependencies into his stop and tour generation model (see Section 3.2.3 below).

3.2.3 Daily Activity-Travel Patterns

There are a number of efforts currently underway to model daily activity-travel behavior, in addition to the work of Ben-Akiva and Bowman (1995) that was described in Section 3.1.4 above. For example, Wen's (1996) dissertation research aims at developing an operational econometric model system for generating complex daily activity-travel patterns. Specifically, his model deals with stop and tour generation and the assignment of stops to tours, as well as the location for each stop and the mode for each tour, in an integrated model system. This research also attempts to incorporate interpersonal dependencies in the model system.

One of the concepts that is integral to the AMOS model (see Section 3.2.1 above) is that of using microsimulation techniques to predict a traveler's adaptation from the baseline (or current) activity-travel pattern. There are two directions being followed currently to develop these baseline daily activity-travel patterns for all the households in a metropolitan area, given the data from a household activity-travel survey and the sociodemographics of all the households in the area (the latter can be generated from census data using a technique such as that of Beckman *et. al.*, 1997). Kitamura (1995) is developing a technique in which the characteristics of the set of activities is generated sequentially using a Markovian approach. The individual's daily activity-travel pattern is formulated as a triple of vectors comprising the set of activities engaged by type, the set of durations for the activities, and the set of locations of the activities engaged.

Vaughn *et. al.* (1997) are approaching the same problem as Kitamura with the goal of generating the daily activity-travel patterns of households and their members in such a way as to replicate the distribution of activity travel patterns at the census block group level and recognizing the interdependencies and linkages that exist within households. This approach assumes that each activity-travel pattern has a "skeletal" structure that can be defined by estimable elements. Once the skeletal structure is specified, it imposes time-space constraints and simplifies the simulation of the remaining details of the activity-travel pattern. The daily activity-travel pattern is to be generated by a two-stage procedure in which the skeletal pattern will be generated based on sociodemographics and then the pattern details will be simulated based on observed probability distributions.

3.2.4 Summary

As with the methodologies section above, this section shows that there is a wealth of recent and on-going activity-based travel demand modeling research, and that this work encompasses a wide range of methodologies as well as phenomena. While much of this work deals only with parts of the overall problem (not the daily or weekly activity-travel behavior of households and their members), the foundations are rapidly being put in place for the development of a comprehensive, integrated modeling framework.

4. WHY ARE WE MAKING PROGRESS NOW IN ACTIVITY-BASED TRAVEL MODELING?

As noted earlier, the activity-based approach to travel demand analysis and modeling has been under development for the past 20 years, so it is reasonable to ask why this approach has seen relatively little application to transportation planning practice in the past, and why there is considerable interest and effort now in developing and applying activity-based travel forecasting models. The first part of this question has been addressed by others in the past. In particular, Kitamura (1988) undertook a careful review and assessment of activity-based travel modeling, with a specific interest in understanding the limited practical applications of the approach up to that time. He came to the conclusion that while the activity-based approach to travel modeling could contribute to many areas of transportation planning, there were a number of reasons why the approach had not been applied more widely to addressing policy and planning problems. The reasons cited by Kitamura include a resistance to change among practitioners and the lack of effort by activity analysts to provide the practitioners with readily usable methods, as well as the perception that activity-based methods are predominantly useful for analyzing the impacts of non-capital intensive options, which can often be examined without systematic analysis tools.

However, the times have changed, and considerable progress is now being made in the activity-based approach to travel demand. Specifically, the development of travel forecasting models founded in the concepts of activity-based travel analysis has gained much momentum in the past few years. Some of these models are being applied on a prototypical basis in some regions and we expect that such models will start to be used in transportation planning practice at the leading MPO's within the next few years.

There are three primary reasons for the recent and on-going progress in activity-based travel modeling; namely, technical reasons, institutional reasons and data availability reasons. Each of these reasons is discussed in the sections below.

4.1 Technical Factors

From the technical point of view, the major reason for the recent advances in activity-based travel modeling is the continued rapid development of computer technology, both hardware and software. Such developments allow researchers to store and process large data sets relatively easily, estimate models that previously could not be estimated because of the required computational resources. In particular, enhanced computational capabilities, coupled with the availability and use of Geographic Information Systems (GIS) to code, store and manipulate geo-referenced data bases is encouraging researchers to develop models that deal with point-to-point movements, rather than zone-to-zone movements (see, for example, Speckman *et. al.*, 1997). Other technical reasons for the recent progress in activity-based travel modeling are advances in the behavioral sciences and in statistical methodologies.

4.2 Institutional Factors

Some years ago the present author wrote a paper addressing the question "Is travel demand analysis and modeling in the doldrums?" (Pas, 1990). The conclusion reached in that paper was that, from a scientific viewpoint, travel demand analysis and modeling was certainly not in the doldrums and that much interesting research was taking place. On the other hand, that paper concluded, travel demand analysis and modeling was very much in the doldrums from an institutional standpoint, since there was little institutional interest in the development of new travel demand modeling techniques and hence very little funding for research and development. (At the same time, funding sources were known to be expressing concerns about the relatively slow rate of progress in the development of activity-based travel forecasting techniques that could be used in planning and policy analysis. This situation, of course, was a classic "catch-22").

If one were to examine the state of travel demand modeling today, from an institutional point of view, one would have to conclude that travel demand analysis and modeling has experienced the "winds of change". In the U.S.A., the Clean Air Act Amendments (CAAA) of 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 provided the impetus for the development of new techniques, through the emphasis these pieces of legislation placed on policies whose impacts could not be adequately addressed with conventional travel demand modeling techniques.[6]

In response to the pressures to develop new and more flexible travel demand models, created by the

Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991, the U.S. Department of Transportation and the Federal Highway Administration, in cooperation with the Environmental Protection Agency and the U.S. Department of Energy, embarked on a program of research. This program, known as the Travel Model Improvement Program, addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytical tools and the integration of these tools into the planning process to better support decision makers. This program has provided a major impetus for the development of new travel forecasting tools and the improvement of existing tools.

Another institutional factor that has had a major role in the current push for the development of new approaches to travel demand forecasting is the law suite brought against the Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area by the Legal Defence Fund of the Sierra Club and Californians for a Better Environment. This suit, which tied up MTC's model development staff for almost 2 years, put planning agencies on notice that their travel forecasting models could be the subject of very careful scrutiny by environmental groups and others with particular interests.[7]

4.3 Data Availability

A third important reason for the recent and continued progress in activity-based travel modeling is the availability of data sets that are well-suited to the development of such models. Specifically, in the United States, MPO's have been moving in recent years away from traditional travel surveys, in which respondents are asked "where did you go?", toward surveys in which respondents are asked "what did you do ?". These latter surveys collect information about activities and the travel undertaken to reach those activities. That is, travel is set in the context of the daily activities undertaken by the respondent. For this reason, such surveys yield higher trip rates, especially for short, infrequent trips by non-motorized modes of travel.

The first metropolitan-wide household travel survey in the USA to collect activity information appears to be that conducted in Boston in 1990 (Stopher, 1992), followed by the survey conducted in Southern California in 1991. Both of these surveys collected information only on out-of-home activities, and the related travel, and the survey format was very similar to a traditional household travel survey, except that the question "where did you go?" was replaced by the question "what did you do?". Some recent household travel surveys, however, have considerably extended the scope of such surveys by collecting information on activity participation (or time use) both in and out-of-the-home, as well as any travel undertaken to reach activities. In particular, surveys undertaken recently in Oregon-Southwest Washington, Raleigh-Durham and San Francisco, all attempted to collect information on all out-of-home activities and the related travel, as well as selected in-home activities, for a 48-hour period (the 48-hour period was chosen in order to capture some of the day-to-day variability that earlier activity-based research showed makes up a significant fraction of the total variability in many aspects of travel behavior).

In the Oregon-Southwest Washington and San Francisco surveys respondents were asked to report in-home activities only if they were 30 minutes or longer in duration. However, in the Raleigh-Durham survey respondents were asked to report all in-home activities, but they were asked to differentiate only those in-home activities that could have been substituted for by out-of-home activities (such as eating, exercising, amusements, etc), while all in-home activities that could only be done at home were designated as "in-home".

The Portland portion of the data from the Oregon-Southwest Washington survey has already stimulated or facilitated a considerable amount of research — see earlier descriptions of work by Golob (1996), Golob & McNally (1995), Lu (1996), Vaughn *et. al.* (1997) and Speckman *et. al.* (1997), while Principio (1996) used the Raleigh-Durham data in her recently completed study of lifestyle and travel behavior. Further, Lawton and his staff at METRO Portland, with the assistance of Cambridge Systematics, Inc., are engaging in the development of a new set of travel demand models that incorporate trip chaining and daily activity schedules, based on the earlier work of Ben-Akiva and Bowman (1995).

The availability of datasets containing both travel and activity information will very likely stimulate and facilitate continuing research and development of activity-based travel models in the immediate future.

5. DISCUSSION & CONCLUSIONS

This paper examines recent and on-going advances in activity-based travel demand modeling. The discussion of the advances in activity-based travel modeling is organized in terms of the methodologies being employed and the phenomena being modeled, and is set in the context of the long and rich tradition of activity-based travel demand analysis.

The paper finds that advances in activity-based travel demand modeling have been made recently at a rapid pace, and that this pace is likely to be sustained by current research and development activities. The paper argues that the recent and current advances are due to a combination of factors, including (1) technical advances in computer hardware and software, statistics, and behavioral sciences, (2) institutional factors that highlight the need for improved travel demand models, and (3) data availability reasons. In addition, the fact that the activity-based approach has been under development for the past 20 years means that this is a very opportune time to be moving the field from a focus on description, analysis and understanding, to an emphasis on modeling and forecasting. In any case, contemporary planning and policy analysis questions cannot adequately be addressed by existing travel demand forecasting tools.

The overview of recent and current work in activity-based travel modeling provided in this paper shows that a wide variety of methodologies are being advanced and employed in modeling a variety of aspects of activity-travel behavior. Some of the methodologies that are being applied are either new or relatively new to the travel demand modeling field, including computational process models, structural equation models, and hazard-based duration models, while discrete choice models (primarily multinomial logit and nested logit models) have previously seen extensive use in travel demand modeling. At the same time, a wide variety of aspects of travel behavior are being modeled, including participation in in-home and out-of-home activities, dependencies among household members, and daily activity-travel patterns. These phenomena are not modeled in traditional approaches to travel demand analysis, yet they require our attention if our models are to be suitable for addressing contemporary planning and policy analysis issues.

Computational process models, in particular, open up completely new possibilities in travel demand modeling. However, these models are quite different from the conventional mathematical-statistical approaches commonly used in travel demand modeling, thus it may take some time and comparative analyses before this approach becomes accepted in the travel forecasting community. Specifically, there is a need to develop methods for calibration and validation of such models.

The diverse methodologies being employed at the current time to model activity-travel behavior, and the variety of phenomena being modeled, is both good news and bad news. The good news is that the activity-based approach is seeing a considerable resurgence of interest, specifically in moving from analysis, description and understanding to modeling and prediction, with a variety of methodologies being applied to model a wide set of phenomena. The bad news, from the point of view of practitioners, is precisely the diversity that makes the field such an exciting and vibrant area of research currently, since the practitioner is faced with the problem of which methodology to select. It might well be some time before the field sees a period of consolidation with one or two methods emerging as standard approaches for application in policy analysis and planning.

At the same time, we should recognize that different tools are needed for different jobs. Thus, while a structural equation model of the type described in Section 3.1.3 does not provide us with link flows, nor an origin-destination matrix, it does allow us to examine some of the implications of changes in sociodemographic characteristics and/or general changes in the transportation system (such as increasing congestion levels throughout the system), without the need to resort to detailed network analysis, while taking into account some important dependencies that are not well accounted for in other modeling approaches. For some planning and policy studies, this level of detail would be quite sufficient. In other cases, of course, this type of model would be quite inadequate.

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REFERENCES

Axhausen, K.; Gärling, T. (1992). Activity-based approaches to travel analysis: Conceptual frameworks, models and research problems. *Transport Reviews*, 12, 323-341.

Beckman, R.J.; Baggerly, K.A.; McKay, M.D. (1997). Creating synthetic baseline populations. *Transportation Research A*, in press.

Ben-Akiva, M.E.; Bowman, J.L. (1995). Activity-based disaggregate travel demand model system with daily activity schedules. Paper presented at the EIRASS Conference on Activity-Based Approaches: Activity Scheduling and the Analysis of Activity Patterns, Eindhoven, The Netherlands.

Bhat, C.R. (1997). Work travel mode choice and number of non-work commute stops. *Transportation Research B*, in press.

Bhat, C.R. (1996a). A hazard-based duration model of shopping activity with nonparametric baseline specification and non-parametric control for unobserved heterogeneity. *Transportation Research B*, 30(3), 189-208.

Bhat, C.R. (1996b). A generalized multiple durations proportional hazard model with an application to activity behavior during the evening work-to-home commute. *Transportation Research B*, 30(6), 465-480.

Bhat, C.R. (1995). A model of post home-arrival activity participation behavior. Manuscript, University of Massachusetts at Amherst.

Chapin, F.S. (1974). *Human Activity Patterns in the City*. John Wiley & Sons, New York.

Clarke, M.I.; Dix, M.C.; Jones, P.M.; Heggie, I.G. (1981). Some recent developments in activity-travel analysis and modeling. *Transportation Research Record*, 794, 1-8.

Damm, D. (1983). Theory and empirical results: a comparison of recent activity-based research. In:

Recent Advances in Travel Demand Analysis. (Eds: Carpenter, S.; Jones, P.) Gower, Aldershot, England.

Ettema, D.A.; Borgers, A.; Timmermans, H. (1995a). A competing risk hazard model of activity choice, timing, sequencing, and duration. Paper presented at the 74th Annual Meeting of the Transportation Research Board, Washington, DC.

Ettema, D.; Borgers, A.; Timmermans, H. (1995b). SMASH (Simulation model of activity scheduling heuristics): Empirical test and simulation issues. Paper presented at the EIRASS Conference on Activity-Based Approaches: Activity Scheduling and the Analysis of Activity Patterns, Eindhoven, The Netherlands.

Ettema, D.F.; Borgers, A.W.J.; Timmermans, H.J.P. (1993). Using interactive computer experiments for investigating activity scheduling behavior. Proceedings of the PTRC 21st Summer Annual Meeting, University of Manchester, P366, 267-282.

Fujii, S.; Kitamura, R.; Monma, T. (1996). A study of commuters' activity patterns for the estimation of induced trips. Manuscript, Kyoto University.

Gärling, T.; Brannas, K.; Garvill, J.; Golledge, R.G.; Opal, S.; Holm, E.; Lindberg, E. (1989). Household activity scheduling. In: *Transport Policy, Management and Technology Towards 2001: Selected Proceedings of the Fifth World Conference on Transport Research*, Vol IV, Ventura, CA: Western Periodicals, pp 235-48.

Gärling, T.; Kwan, M.P.; Golledge, R.G. (1994). Computational-process modelling of household travel decisions: Conceptual analysis and review. *Transportation Research B*, 28(5), 355-364.

Golledge, R.G.; Kwan, M.P.; Gärling, T. (1994). Computational process modeling of household travel decisions using a geographical information system. *Papers in Regional Science*, 73(2), 99-117.

Golob, T.F. (1996). A model of household demand for activity participation and mobility. Presented at the Conference on Theoretical Foundations of Travel Choice Modeling, Stockholm, Sweden.

Golob, T. F (1990a). Structural equation modeling of travel choice dynamics, In: *Developments in Dynamic and Activity-based Approaches to Travel Analysis.* (Ed: Jones, P.) Avebury, Aldershot, England.

Golob, T. F. (1990b) The dynamics of household travel time expenditures and car ownership decision, *Transportation Research A*, 24 (6), 443-463.

Golob, T.F.; Bradley, M.A.; Polak, J.W. (1996). Travel and activity participation as influenced by car availability and use. Presented at the 75th Annual Transportation Research Board Meeting, Washington, DC.

Golob, T.F.; McNally, M.G. (1995). A model of household interactions in activity participation and the derived demand for travel. Presented at the EIRASS Conference on Activity-Based Approaches: Activity Scheduling and the Analysis of Activity Patterns.

Golob, T.F.; Meurs, H. (1987). A structural model of temporal change in multi-modal travel demand, *Transportation Research A*, 21(6), 391-400.

Hagerstrand, T. (1970). What about people in regional science? *Papers in Regional Science*, 24, 7-21.

Hagerstrand, T. (1973). The Impact of Transport on the Quality of Life. *Fifth International Symposium on Theory and Practice in Transport Economics*, Greece.

Hamed, M.M.; Mannering, F.L. (1993). Modeling travelers' postwork activity involvement: toward a new methodology. *Transportation Science*, 27(4), 381-394.

Heggie, I.G. (1978). Putting behaviour into behavioural choice models. *Journal of the Operational Research Society*, 29(6), 541-550.
Hensher, D.A. (1996). Personal communication describing a proposed research project on activity-based travel modeling.
Jones, P. (1995). Contribution of activity-based approaches to transport policy analysis. Paper presented at the Workshop on Activity Analysis, Eindhoven, The Netherlands, May.
Jones, P.; Dix, M.; Clarke, M.; Heggie, I. (1983). *Understanding Travel Behaviour*. Gower, Aldershot.
Jones, P.; Koppelman, F.; Orfeuil, J.P. (1990). Activity analysis: state-of-the-art and future directions. In: *Developments in Dynamic and Activity-Based Approaches to Travel*. (Ed: Jones, P.) Avebury, Aldershot, 34-55.
Joreskog, K.G.; Sorbom, D. (1995). *LISREL 8*. Scientific Software International, Inc, Chicago.
Kitamura, R. (1996). Activity-Based Travel Demand Forecasting and Policy Analysis. Paper presented at the TMIP Conference on Activity-Based Travel Forecasting, New Orleans, LA, June 2-5, and published in these proceedings.
Kitamura, R. (1995). Generation of synthetic daily activity-travel patterns: Outline of the approach. Technical Report No. 39, National Institute of Statistical Sciences, Research Triangle Park, NC.
Kitamura, R. (1988). An evaluation of activity-based travel analysis. *Transportation*, 15(1/2), 9-34.
Kitamura, R.; Lula, C.V.; Pas, E.I. (1993). AMOS: An activity-based, flexible and behavioral tool for evaluation of TDM measures. Proceedings of the 21st PTRC Summer Annual Meeting, 1993.
Kitamura, R.; Pas, E.I.; Lula, C.V.; Lawton, T.K.; Benson, P.E. (1996). The sequenced activity mobility simulator (SAMS): An integrated approach to modeling transportation, land use and air quality. *Transportation*, 23(2), 267-291.
Kitamura, R.; Pendyala, R.M.; Pas, E.I.; Reddy, P. (1995). Application of AMOS, an Activity-Based TCM Evaluation Tool, to the Washington, DC Metropolitan Area. 23rd European Transport Forum: Proceedings of Seminar E, Transportation Planning Methods, PTRC Education and Research Services, Ltd., London, pp 177-190.
Kitamura, R.; Yamamoto, T.; Fujii, S.; Sampath, S. (1996). A Discrete-Continuous Analysis of Time Allocation to Two Types of Discretionary Activities Which Accounts for Unobserved Heterogeneity. In: *Transportation and Traffic Theory*, (Ed.: Lesort, J.B.), Elsevier, Oxford, 431-453.
Kraan, M. (1995). In search for limits to mobility growth with a model for the allocation of time and money. Paper presented at the EIRASS Conference on Activity-Based Approaches: Activity Scheduling and the Analysis of Activity Patterns, Eindhoven, The Netherlands.
Kuhn, T.S. (1970). *The Structure of Scientific Revolutions*. University of Chicago Press, Chicago, IL.
Kurani, K.S.; Kitamura, R. (1996). Recent developments and the prospects for modeling household activity schedules. A report prepared for the Los Alamos National Laboratory, Institute of Transportation Studies, University of California, Davis, CA.
Kurani, K.S.; Lee-Gosselin, M.E.H. (1996). Synthesis of past activity analysis applications. Presented at the TMIP Conference on Activity-Based Travel Forecasting, New Orleans, LA, June 2-5, and published in these proceedings.
Lawson, C. (1996). Household Travel-Activity Decisions). Draft Dissertation Proposal, Urban

Studies/Regional Science, Portland State University.
Lu, X. (1996). A study of the interrelationships among socio-demographics, time use and travel behavior. Unpublished M.S. thesis, Department of Civil & Environmental Engineering, Duke University.
Lu, X.; Pas, E.I. (1997). A structural equation model of the relationships among socio-demographics, activity participation and travel behavior. To be presented at the 76th Annual Meeting of the Transportation Research Board, Washington, DC.
Mannering, F.; Murakami, E.; Kim, S.G. (1994). Temporal stability of travelers' activity choice and home-stay duration: some empirical evidence. *Transportation*, 21(4), 371-392.
Newell, A.; Simon, H.A. (1972). *Human Problem Solving*. Prentice-Hall, Englewood Cliffs, NJ.
Oi, W.Y; Shuldiner, P.W. (1962). *An Analysis of Urban Travel Demands*. Northwestern University Press, Evanston, IL.
Pas, E.I. (1996). Time and travel demand modeling: Theory, data collection and models. Paper presented at the Conference on Theoretical Foundations Of Travel Choice Modeling, Stockholm, Sweden.
Pas, E.I.; Harvey, A.S. (1991). Time use research and travel demand analysis and modeling. Paper presented at the Sixth International Conference on Travel Behavior, Quebec City, Quebec.
Pas, E.I. (1990). Is travel demand analysis and modelling in the doldrums? In*: New Developments in Dynamic and Activity-based Approaches to Travel Analysis*. (Ed: Jones, P.) Avebury, Aldershot, 3-27.
Pas, E.I. (1985). State-of-the-art and research opportunities in travel demand: Another perspective. *Transportation Research A*, 19, 460-464.
Ponnaluri, R.V.N.N. (1995). Analysis of vehicular stop times: Implications for cold starts. Unpublished MS Thesis, Department of Civil & Environmental Engineering, Duke University, Durham, NC.
Principio, S. (1996). Time-use as a manifestation of life style: An examination of the variations in sociodemographics and travel behavior across life style groups. Unpublished M.S. Thesis, Duke University, Durham, NC.
Purvis, C.L.; Iglesias, M.; Eisen, V.A. (1996). Incorporating work trip accessibility in non-work trip generation models in the San Francisco Bay Area. Presented at the 75th Annual Transportation Research Board Meeting, Washington, DC, January 1996.
RDC, Inc. (1995). Activity-based modeling system for travel demand forecasting. Prepared for the Metropolitan Washington Council of Governments, September.
RDC, Inc. (1993). The Next Generation of Transportation Forecasting Models: The Sequenced Activity-Mobility Simulator. Draft Final Report, Prepared for the Federal Highway Administration, Contract No. DTFH61-92-01891.
Recker, W.W. (1995). The household activity pattern problem: General formulation and solution. *Transportation Research B*, 29(1), 61-77.
Recker, W.W.; McNally, M.G.; Root, G.S. (1986a). A model of complex travel behavior: Part I: Theoretical development. *Transportation Research A*, 20 (4), 307-318.
Recker, W.W.; McNally, M.G.; Root, G.S. (1986b). A model of complex travel behavior: Part II: An operational model. *Transportation Research A*, 20(4), 319-330.
Speckman, P.; Vaughn, K.M.; Pas, E.I. (1997). A continuous spatial interaction model: Application to home-work travel in Portland, Oregon. To be presented at the 76th Annual Meeting of the

Transportation Research Board, Washington, DC.
Stopher, P.R. (1992). Use of an activity-based diary to collect household travel data. *Transportation*, 19, 159-176.
Townsend, T.A. (1987). *The Effects of Household Characteristics on the Multiday Time Allocations and Travel Activity Patterns of Households. and Their Members*. Unpublished Ph.D. Dissertation, Northwestern University, Evanston, IL.
Vaughn, K.M.; Speckman, P.; Pas, E.I. (1997). Generating household activity-travel patterns (HATPs) for synthetic populations. To be presented at the 76th Annual Meeting of the Transportation Research Board, Washington, DC.
Vause, M. (1995). A Behavioral Rule-Based Model of Activity Chains Generation and Scheduling. Paper presented at the EIRASS Conference on Activity-Based Approaches: Activity Scheduling and the Analysis of Activity Patterns, Eindhoven, The Netherlands.
Wen, C.H. (1996). Development of Stop Generation and Tour Formation Models for the Analysis of Travel/Activity Behavior. Dissertation Proposal, Department of Civil Engineering, Northwestern University.

ENDNOTES

[1] Some characterize the difference between economists and sociologists as follows: economists study the choices that people make, while sociologists study why people have no choices.

[2] It should be noted that with the development of more flexible and powerful discrete choice models, such as the nested logit model, researchers are now beginning to apply these models to an interrelated set of choices. For more details, see Section 3.1.4 of the this paper.

[3] The AMOS model is described in detail by Kitamura in another paper in this volume, so the interested reader can consult that paper for more detail than is provided here. Kitamura's paper also describes another prototype CPM, called PCATS, which is based on the notion of time-space prisms developed by Hagerstrand (1970). Again, the reader interested in more details can consult Kitamura's paper in this volume.

[4] The term "failure" was originally used in this literature because of the applications in medical science and industrial engineering, since the former dealt with the duration of a patient's survival after surgery or treatment, while the latter dealt with the length of time before a part failed.

[5] Specifically, Bhat (1996a) incorporates a non-parametric baseline function as well as non-parametric control for heterogeneity.

[6] While air quality has been the focus recently in the U.S.A., in other industrialized countries there is considerable interest in the concept of "sustainability". It is interesting to note that both of these concerns lead to a need for better models and analysis tools — tools that can deal with demand management strategies and that are more accurate and precise.

[7] In part to protect against criticisms of their work, it has become standard for MPO's and other agencies developing travel demand models or undertaking household travel surveys, to constitute a group of "experts", generally referred to as a Peer Review Group or Peer Review Panel, to advise the agency and/or the consultant undertaking the model development work.